UAV Flight Demonstration Project Spring 2005
Mission Objectives and Flight Planning Document

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National Oceanic and Atmospheric Administration

(OAR) Oceans and Atmospheric Research
(ETL) Environmental Technology Laboratory
(AL) Aeronomy Laboratory
(CMDL) Climate Monitoring and Diagnostics Laboratory
(NOS) National Ocean Service
(FSL) Forecast Systems Laboratory

Contents

1.0 Background.
1.1 The NOAA Scientific Mission.

1.2 The NOAA Operational Mission.

2.0 Science Instruments and Objectives.
2.1 Gas Chromatograph/Ozone (GC/OZ) Instrument
2.1.1 Gas Chromatograph/Ozone Primary Objectives
2.1.2 Gas Chromatograph/Ozone Secondary Objectives

2.2 Ocean Color (OC) Sensor.
2.2.1 Ocean Color Primary Objectives
2.2.2 Ocean Color Secondary Objectives

2.3 Passive Microwave Vertical Sounder (PMVS) Sensor
2.3.1 Passive Microwave Vertical Sounder Primary Objectives
2.3.2 Passive Microwave Vertical Sounder Secondary Objectives

3.0 Operational Instruments and Objectives.
3.1 Cirrus Digital Camera System (DCS).
3.1.1 Cirrus Digital Camera System Primary Objectives
3.1.2 Cirrus Digital Camera System Secondary Objectives

3.2 Wescam 14 EO/IR SkyBall Camera
3.2.1 EO/IR Skyball Camera Primary Objectives
3.2.2 EO/IR Skyball Camera Secondary Objectives

4.0 Flight Planning Information
4.1. Integration Test Flights

4.2 Scientific and Operation Mission Flights
4.2.1. Flight 1a: Channel Islands Survey/OC Spiral (~ 6 hours)
4.2.2 Flight 1b: Channel Islands Survey/Day - Night (~ 4 hours)
4.2.3 Flight 2: Sounding Curtain/Atmospheric Chemistry (~ 6 hours)
4.2.4 Flight 3: Cross-Tropopause Sampling (~12.5 hours)
4.2.5 Flight 4: Atmospheric Rivers Sampling (~ 21 hours)
4.2.6 Flight 5: Ocean Color Profile/Trinidad Head Profile (~ 11 hours)

5.0 Altair Flight Plans: Flight tracks, flight profiles, and flight waypoints

1.0 Background.

Unmanned aerial vehicles (UAVs) have great potential to meeting NOAA's mission requirements in the coming years. UAVs will be complementary to existing ground-based, airborne, and space-based systems. Important requirements identified in the NOAA 2005-2010 Strategic Plan that can be addressed by UAV platforms and their sensor payloads include detection and attribution of climate change, improved 1 to 14 day weather predictions, satellite calibration and validation, hydrological monitoring, fisheries surveillance and enforcement, atmospheric and oceanic research, nautical charting, and ecosystem monitoring.

UAVs are a relatively new asset available to NOAA research and operations. The importance of adding UAVs and newer technology to NOAA's mission is described in the 2007 Annual guidance Memorandum from the NOAA Administrator (VADM Lautenbacher):

> "*We must move new but proven observing systems into an operational environment and redirect associated resources and research toward exploring new technologies, such as unmanned aerial vehicles, to meet future requirements*."

To this end, a series of flights of a NOAA instrument suite on the General Atomics Aeronautical Systems, Inc. (GA-ASI) Altair UAV is being planned for Spring 2005. The purpose of the 2005 Altair flight trials is to demonstrate the value of a Medium Altitude Long Endurance (MALE) UAV platform in supporting NOAA research and operational needs. UAV platforms have the potential to carry instrument payloads to remote locations in a manner that could not otherwise be achieved with crewed aircraft, and to reduce the costs of meeting operational requirements.

The Altair flights are being conducted by NOAA in cooperation with the NASA Dryden Flight Research Center. The Altair payload will include remote and *in situ* instruments for measurements of ocean color, and atmospheric composition and temperature, and a surface imaging and surveillance system. In situ composition measurements will include ozone and long-lived gases such as halocarbons, sulfur hexafluoride, and nitrous oxide. These gases are all greenhouse gases that contribute to anthropogenic climate forcing. Six mission flights are planned for a total of 53 hours of flight time. Flights will reach altitudes up to 45,000 ft and have durations up to 20 hours.

The purpose of this document is to summarize the primary and secondary mission objectives for both the science and operational uses, and to provide a set of flight plans and requirements. These objectives are consistent with the mission plan and flight requirements document developed during the definition phase of the project.

1.1 The NOAA Scientific Mission.

NOAA has research needs in a number of areas that can be addressed by UAV flights with payloads of in situ and remote sampling instruments. For example, airborne sampling is required for air quality and ocean studies, for measuring the diurnal patterns of biologically produced gases that impact climate change, and for research in the remote polar regions to address stratospheric ozone depletion. The need for atmospheric trace gas research is defined within the

Atmospheric Composition and Climate Program under the Climate Goal of the NOAA Strategic Plan. The flight demonstration project with the Altair will include instruments for sampling of long-lived trace gases, ozone, ocean color, and remote temperature and water vapor profiles (see **Table 1** and **Figure 1a, 1b**).

Table 1. Altair Instrument Payload

Science Sensors[1]	**Technique**	**Observables**
Gas Chromatograph (GC)	Gas chromatography	Long-lived gases: sulfur hexafluoride (SF_6), nitrous oxide (N_2O), and the halogenated gases CFC-11, CFC-12, and H-1211.
Ozone (OZ)	Ultraviolet absorption	Ozone
Ocean color (OC)	7-band optical radiance detection	Chlorophyll-a
Passive Microwave Vertical Sounder (PMVS)	Microwave and infrared sensor suite	Temperature and moisture profiles, and cloud parameters
Operational Sensors		
Digital Camera System (DCS)	True color camera	Surface mapping and monitoring
Electro-Optical Infrared sensor (EO/IR)	Visible and infrared sensors with pointing capability	Surface mapping and monitoring

[1]The Gas Chromatograph (GC) and Ozone photometer (OZ) sensors are combined into the GC/OZ instrument enclosure. The Ocean color (OC) sensor and Passive Microwave Vertical Sounder (PMVS) are combined into the OC/PMVS instrument enclosure.

A gas chromatograph built specifically to operate on the Altair UAV will make in situ measurements of the long-lived gases sulfur hexafluoride (SF_6), nitrous oxide (N_2O), the halogenated gases CFC-11, CFC-12, and H-1211. All of these gases are radiatively active in the atmosphere and, hence, contribute to anthropogenic climate forcing. The distribution of N_2O and the halogenated gases influence the chemical loss of ozone, in part because the halogenated gases contain chlorine and bromine atoms. Measurements of these gases in the upper troposphere and lower stratosphere reachable by Altair will demonstrate the value of UAV technology in understanding the distribution of these important gases and how their distribution and abundances are changing and will change in the future.

Ozone will be measured through optical absorption. Ozone is a key radiatively active trace gas and is produced photochemically in both the troposphere and stratosphere. In the stratosphere, ozone protects life on Earth from harmful ultraviolet radiation. Halogenated gases released in human activities lead to ozone depletion throughout the stratosphere. Ozone in the troposphere is formed in natural chemical reactions and in reactions caused by the presence of anthropogenic emissions. Understanding how ozone is produced and destroyed in the atmosphere is key to making accurate predictions of future ozone amounts.

Ocean color will be measured with a multi-channel optical radiance sensor. Remote sensing of ocean color provides a measure of the concentration of chlorophyll-a in the upper layers.

Chlorophyll-a is a measure of the primary productivity of the upper ocean layer, which affects all ocean life. The oceans take up about 50% of anthropogenic CO_2 emissions. Understanding CO_2 uptake is an important goal of the Carbon America Program within the NOAA Climate Goal. The Altair UAV measurements will be used to understand how aerosols, sun glint, and ocean foam coverage systematically affect retrievals of ocean color from satellites.

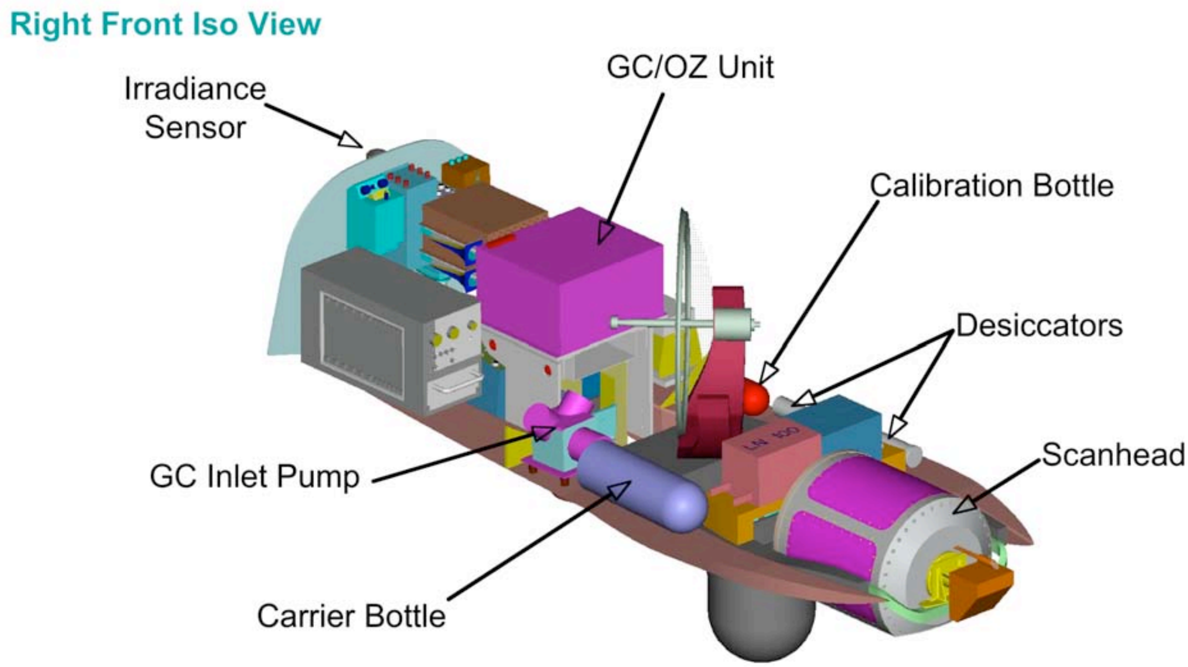


Figure 1a. Schematic of the instrument payload as installed in the nose of the Altair UAV. The Scanhead contains the PVMS and OC sensors. The Irradiance sensor is the upward-looking component of the OC sensor system. The GC/OZ unit, Calibration Bottle, GC Inlet Pump, Carrier Bottle, and Dessicators are components of the GC/OZ instrument. Figure courtesy of GA-ASI.

Vertical profiles of temperature and water vapor will be measured in the cold-frontal region of an extratropical cyclone using a multi-channel passive microwave sounder. The pre-cold-frontal moisture flows caused by extratropical cyclones that approach the West Coast of the United States each winter plays a critical role in transporting water vapor into the coastal mountains, resulting in orographic enhancement of precipitation that can generate devastating flooding. The low-level jet (LLJ), which resides at and below approximately 1 km MSL, represents the boundary-layer component of a deeper corridor of spatially concentrated water vapor in the pre-cold-frontal environment. Because these corridors tend to be quite narrow (<1000 km wide) relative to their length scale (>2000 km), and yet are responsible for almost all of the meridional water vapor transport at midlatitudes, they are referred to as atmospheric rivers (ARs). Most (~75%) of the water vapor transport within these rivers occurs within the lowest 2.5 km of the atmosphere. In addition to causing flooding rains in the coastal mountains and playing a critical role in the global water cycle, land-falling atmospheric rivers are integrally tied to water resource issues in the semi-arid West, where a majority of snowfall in the higher elevations ultimately provides fresh water to the population. Predicting the evolution of these filamentary moisture flows as they move across the ocean and understanding their moisture content and transport properties is a current area of research. Research and improved measurement capabilities will ultimately lead to better long-term predictions of rainfall near the west coast and a reduced impact on humans. The Altair measurements will attempt to sample with high precision and accuracy the moisture and temperature profiles in an atmospheric river over the northeastern Pacific Ocean.

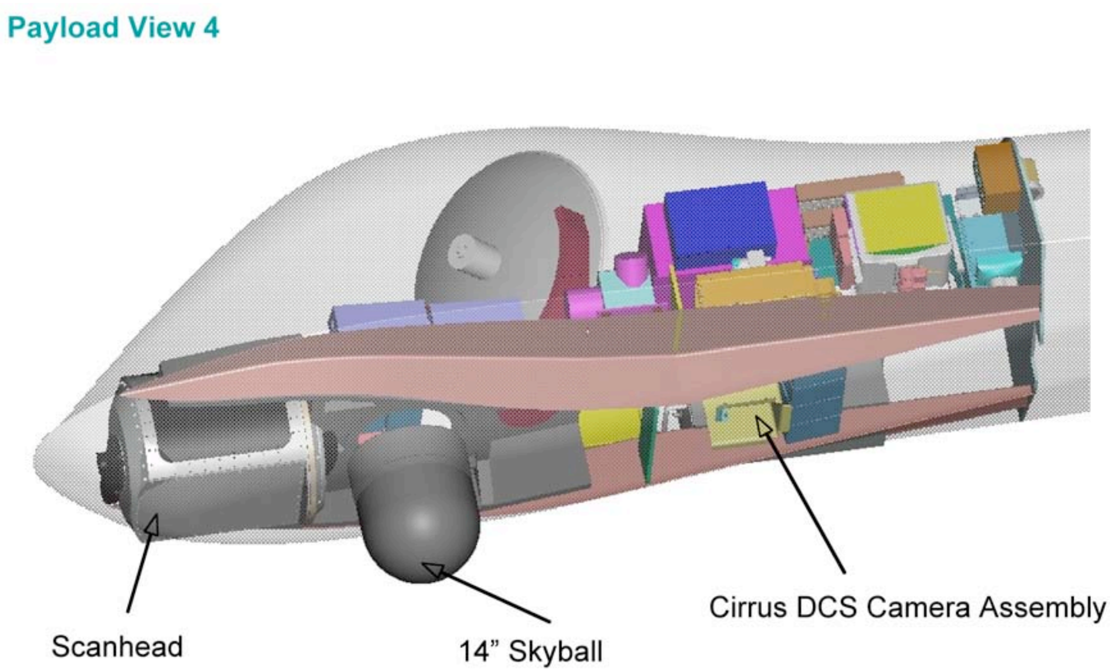


Figure 1b. Schematic of the instrument payload as installed in the nose of the Altair UAV. The Skyball is the Electro-Optical Infrared (EO/IR) sensor. Figure courtesy of GA-ASI.

1.2 The NOAA Operational Mission.

NOAA is congressionally mandated to map the nation's coastal boundary. This activity is carried out within the National Geodetic Survey (NGS) of NOAA's National Ocean Service (NOS). The national shoreline provides the baseline for establishing the United States' territorial boundaries and Exclusive Economic Zone (EEZ), as well as a navigational reference for mariners and a geographic reference for coastal managers and other constituents. Fishing by foreign nations within the United States' Exclusive Economic Zone (EEZ) is an issue on the open seas.

Additionally, NGS collects aerial photography for the mapping and cataloging of terrestrial and benthic habitat in NOAA's National Marine Sanctuaries. The National Marine Sanctuary Program was created in 1972 and is administered by the National Oceanic and Atmospheric Administration (NOAA). Currently these sanctuaries include over 18,000 square miles of water and land. There are plans to create a new sanctuary in the Northwest Hawaiian Islands, currently the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve, encompassing nearly 120,000 square miles. Patrolling this large of an area for illegal fishing and unpermitted activities presents many challenges.

Within NGS, the Remote Sensing Division's (RSD) Research and Development Team is tasked to develop new sensors and platforms for shoreline mapping to increase efficiency and the governments return on investment. Recent advances in UAV technology present new platforms to meet NOAA's needs. Conducting mapping missions on a UAV provides multiple benefits. The Altair platform, based on published specifications, provides extended operational capability allowing enhanced mapping missions (both temporally and spatially). The platform is well suited to flying repetitive or dangerous missions where pilot fatigue and/or safety are an issue.

The Altair UAV will use a Digital Camera System (DCS) and Electro-Optical Infrared (EO/IR) Sensor to demonstrate how these operational needs could be met in future UAV flights (see **Table 1** and **Figure 1a, 1b**). The DCS will be used in shoreline mapping and in along-shore/inland feature characterization for habitat mapping/ecosystem monitoring. The demonstration will focus on the Channel Islands National Marine Sanctuary near the coast of California. The EO/IR system will be used for day/night fisheries surveillance and enforcement, and marine mammal surveys.

2.0 Science Instruments and Objectives.

The Altair science payload consists of four detectors housed in two separate instrument enclosures (see **Figure 1a, 1b**). Two of the detectors are the *in situ* gas chromatograph (GC) and ozone photometer (OZ) for the measurement of long-lived trace gases and ozone, respectively. These detectors are housed collectively in the (GC/OZ) instrument. The other two detectors are the ocean color sensor (OC) and the passive microwave vertical sounder (PMVS) for water vapor and temperature. These detectors are housed collectively in the (OC/PMVS) instrument. Each of these sensors is associated with distinct science objectives (see summary in **Table 2**). The combined objectives will be met through common flight profiles as outlined below in Section 4.0. Details of the science sensors are outlined below.

Table 2. Summary of Flight Objectives for Altair Instrument/Sensor Payload

Science Sensors	**Primary/*Secondary* Objectives**
Gas Chromatograph (GC) and Ozone photometer (OZ)	1) Polar air mass sampling 2) Aura satellite validation *1) Stratospheric mean ages, total chlorine, and total bromine.* *2) Lower tropospheric ozone measurements* *3) Intercomparison of Altair airborne measurements with NOAA ground-based observations*
Ocean color (OC)	1) OC radiance correction *1) OC sun glint and foam correction* *2) Near-coastal satellite OC validation*
Passive microwave vertical sounder (PMVS)	1) Atmospheric rivers sectional flights 2) Sounding curtain demonstration *1) Real-time sounding for forecasting purposes*
Operational Sensors	
Digital Camera System (DCS)	1) Prove platform capabilities for collecting mapping quality data *1) Shoreline feature attribution* *2) Enforcement/surveillance*
Electro-Optical Infrared sensor (EO/IR)	1) Enforcement/surveillance *1) Examine capabilities for marine mammal surveys*

2.1 Gas Chromatograph/Ozone (GC/OZ) Instrument

J. W. Elkins and S. J. Oltmans (NOAA/CMDL), Principal Investigators

Gas Chromatograph (GC)

Description: Two-channel (ACATS-II class) gas chromatograph. (ACATS-II is the Airborne Chromatograph for Atmospheric Trace Species instrument developed in NOAA/CMDL for aircraft and balloon operations.)
Observables: Trace gases: nitrous oxide (N_2O), sulfur hexafluoride (SF_6), halocarbons (CFC-11, CFC-12, Halon-1211) with data reported every 70 seconds.

The 2-channel GC utilizes rapid gas chromatography to measure five trace gases every 70 sec. Each channel is comprised of a 12-port valve for sample injection, a 1.5 cm^3 sample loop, narrow bore (2.2 mm id) packed columns, and an electron capture detector. Calibration is performed in-flight every 5 min through the analysis of a standardized cylinder of dried whole air. Further calibration is performed in the laboratory to characterize detector response functions over the full ranges of trace gas mixing ratios measured during flights. In the post-flight phase, chromatograms are processed into mixing ratio data with error estimates for each measurement.

Ozone (OZ) Sensor:
Description: Ozone photometer
Observables: Ozone (O_3) abundances which are typically less than 100 parts per billion (ppb) in the lower troposphere and increase up to 5000 ppb in lower stratosphere. The sampling period is 10 sec.

The OZ photometer relies on the absorption of UV light (254 nm) by the ozone present in air as it flows through a 15-cm long absorption cell at approximately 1 L min^{-1}. The intensities of light reaching the photodiode detector after alternately passing through ozone-free air and sampled air in the cell are used in a simple Beer-Lambert Law calculation of the ozone mixing ratio. The photometer is calibrated in the laboratory before and after flights.

2.1.1 Gas Chromatograph/Ozone Primary Objectives

1) Polar air mass sampling. Measurements within a polar air mass in the lower stratosphere (~33,000+ ft, or ~10+ km) are a high priority. Polar air masses will have higher ozone and lower concentrations of the trace gases CFC-11, CFC-12, halon-1211, N_2O, and SF_6 than mid-latitude air masses. The Arctic winter of 2004-2005 has been one of the coldest on record. As such, it has the potential to have one of the highest ozone depletions observed in the Northern Hemisphere (NH), and a small ozone hole may form similar to those observed every year in the springtime Southern Hemisphere. The breakup of a potentially strong polar vortex in the NH will allow us to investigate mixing processes with greater time and spatial resolution using Altair than using other platforms or sensor techniques. Polar stratospheric vortex incursions are often present in the NH mid latitudes and subtropics in the November to April time period. Forecast projections of potential vorticity at various altitudes by the NOAA Aeronomy Laboratory can be used for determining likely locations and times of incursions. The success of this objective depends on suitable air masses coming into the operational range of the Altair UAV. GC/OZ Flights through such incursions are needed for polar air mass incursion studies.

2) Aura satellite validation. The GC/OZ instrument measures ozone, CFC-11, CFC-12, and nitrous oxide. These trace gases are also measured by the NASA Aura Satellite, an atmospheric chemistry satellite. Within 2-3 weeks before a scheduled flight, CMDL can obtain data on Aura sampling locations. GC/OZ flights near Aura sampling locations and at associated sampling times would be needed for Aura validation.

2.1.2 Gas Chromatograph/Ozone Secondary Objectives

1) Stratospheric mean ages, total chlorine, and total bromine. At altitudes above the tropopause (~33,000 ft or ~10 km) the GC observations can be used to calculate the mean ages of stratospheric air masses (from SF_6) and the total abundances of chlorine and bromine (from CFC-11, CFC-12, halon-121, and N_6O). Age-of-air is the time elapsed since an air parcel crossed the tropopause on ascent into the stratosphere. Age-of-air is a useful constraining parameter in validation of atmospheric models. GC/OZ flights at altitudes in the lower stratosphere (above the tropopause) are needed for air mass age studies.

2) Lower tropospheric ozone measurements. The five trace gases measured by the GC, along with tropospheric ozone, are all greenhouse gases. Their atmospheric distribution and relation to sources and sinks is of importance in understanding the future abundances of these gases. GC/OZ measurements over known polluted regions and the marine boundary level (1-2 km altitude) offer a diverse range of concentrations, and should be performed.

3) Intercomparison of Altair airborne measurements with NOAA ground-based observations. The closest possible high-altitude flyover of the NOAA CMDL station at Trinidad Head, CA, is required to get an intercomparison of temperature, pressure, ozone, water profiles, and flask measurements with the GC/OZ sensor. The site is located at (41.05 N, 124.15 W, and 107' MSL near Eureka, CA. Ozone sondes are normally launched once per week (either Wednesday or Thursday) from Trinidad Head, CA. The launch day can potentially be changed to coincide with a UAV flight. In addition, CMDL operates a small aircraft for weekly *in situ* sampling overflights of the Trinidad Head site. The aircraft carries an automated sampler for many trace gases and an *in situ* ozone sensor that might help with ground truth validation. Coordination of CMDL's Trinidad Head sampling flights with Altair overpasses is important for correlation of GC/OZ data with other truth data.

If an overflight of Trinidad Head is not possible, an ozonesonde and water sonde could be launched by CMDL from a waypoint nearby the GA-ASI airstrip at Gray Butte. This launch could be performed in conjunction with raob sonde launches needed for the PMVS sounding curtain demonstration.

2.2 Ocean Color (OC) Sensor.
J. Churnside, Principal Investigator

Description: Multi-channel optical radiance sensors: (1) Nadir 7-band radiance sensor (3^{o} beamwidth) and (2) Zenith 7-band irradiance sensor (hemispheric beam)
Observables: Ocean chlorophyll-a using upwelling water radiance, 400-700 nm (sensitivity 6.5×10^{-7} µW cm^{-2} nm^{-1} sr^{-1}, spectral resolution 10-20 nm) and downwelling irradiance, 400-700 nm (sensitivity 8.7×10^{-3} µW cm^{-2} nm^{-1})

The OC instrument includes a nadir-staring seven-channel optical radiance sensor and a zenith-looking seven-channel optical irradiance sensor. The radiance unit is installed inside the PMVS sensor drum. Both sensors (radiance and irradiance) use the PMVS data acquisition computer for archiving their raw data, and are powered through the OC/PMVS instrument. Both of these units are hermetically sealed and thermally stabilized. The OC radiance sensor can only collect useful data if there is clear air between the aircraft and surface. No specific flight profiles are required to satisfy OC mission objectives, but in-flight calibration profiles are required. Useful operational data can be collected at any altitude under clear sky conditions before or after the calibration flight.

2.2.1 Ocean Color Primary Objectives

1) OC Radiance Correction. The principle objective for the OC reflectivity correction study is to observe upwelling radiance spectra at a variety of altitudes corresponding to a range of aerosol optical depths. These vertical profile data should be acquired in clear (cloudless) skies with light winds (< 5 m s^{-1}) and for moderate solar zenith angles ($> 30°$, $< 60°$). The data will be used to study the impact of aerosols on OC radiance spectra and determine the potential for correcting airborne and satellite-based radiances for aerosol content.

2.2.2 Ocean Color Secondary Objectives

1) OC Sun Glint and Foam Correction. High-resolution optical images of the surface (nadir view) from the on-board Cirrus Digital Camera System (DCS) at any flight altitude and in clear air would be useful to supplement the nadir-viewing video imagery from the PMVS for glint and foam determination. The high resolution imagery would specifically be useful in helping quantify the fractional amount of sun glint and ocean foam coverage, both of which increase with surface wind speed at low-to-moderate wind speeds. The impact of foam and sun glint on OC spectra will be studied to evaluate the potential for correction of OC airborne and satellite data.

2) Near-Coastal Satellite OC Validation. The third science objective is validation of satellite ocean color data in the near shore zone. To satisfy this objective, the near shore data collected as part of other missions will be compared with satellite ocean color data. The covariance of the UAV data over a satellite pixel will be used to estimate the uncertainty in the satellite measurement caused by the variability in water properties on scales smaller than the satellite pixel. We will also examine the bias introduced in satellite estimates of chlorophyll concentration. This bias arises through the nonlinear algorithm (band ratio calculation) to estimate chlorophyll concentration from radiance.

2.3 Passive Microwave Vertical Sounder (PMVS) Sensor
B. Orr, and M. Klein (NOAA/ETL), Principal Investigators

Description: Multi-channel sensor array:
(1) Nadir 50-57 GHz 11-channel temperature sounder (3.5^o beamwidth);
(2) Nadir 183-GHz 7-channel moisture sounder (1.8^o beamwidth)
(3) Nadir 340 GHz cloud radiometer (1.8^o beamwidth)
(4) Nadir 380 GHz 3-channel moisture sounding radiometer (1.8^o beamwidth)
(5) Nadir 10 μm infrared sensor (1.8^o beamwidth)
(6) Nadir CCD color video camera, 380 x 470 pixels (29.1^o x 36.6^o FOV)
Observables:
(1) Temperature profile (0.3 K precision, 1.5 km vertical resolution)
(2) Moisture profile (15% RH precision, 1.5 km vertical resolution)

(3) Cloud top ice detection
(4) Moisture profiles in clear air (20% RH precision, 2 km vertical resolution)
(5) Cloud top temperature (1 K precision)
(6) Local in-flight video imagery of surface and cloud tops; cloud top altitude via stereoscopy.

The PMVS instrument includes several nadir-staring microwave radiometers along with a nadir-staring infrared radiometer and video camera. The two primary radiometers are a 50-57 GHz temperature profiling unit and a 183-GHz moisture profiling unit. These two radiometers will be used to measure the thermodynamic state across Pacific low-level jets with a horizontal spatial resolution of ~1-2 km. Additional microwave radiometers are included to measure cloud water content (a 340 GHz unit), cloud top temperature (a 10 µm IR unit), and redundant measurements of moisture profiles (a 380 GHz unit). Each of the above radiometers is internally calibrated, although absolute external calibration is required by two means: 1) pre-flight and post-flight calibration using a pair of blackbody standards (to be supplied by NOAA/ETL), and 2) overflight calibrations of opportunity using radiosonde temperature and humidity profiles.

The microwave sensors can operate during all weather conditions except within or over heavy precipitation. However, scientifically useful data can only be collected above altitudes of ~15,000 - 20,000 ft. The data is most useful when observed flying over the highest cloud tops, and at the highest altitudes achievable by Altair (~41,000 ft - 45,000 ft).

2.3.1 Passive Microwave Vertical Sounder Primary Objectives

1) Atmospheric rivers sectional flights. Atmospheric rivers typically originate within the tropical Integrated Water Vapor (IWV) reservoir, which is bounded on the north at ~10^{o}-15^{o} latitude by the Inter Tropical Convergence Zone (ITCZ). Atmospheric rivers (ARs) are channeled approximately northeastward by geostrophic winds driven by ~NW-SE pressure gradients. These gradients are the result of extratropical cyclones with frontal boundaries that run in the ~NE-SW directions (along the track of the river). The synoptic state leading to the necessary frontal conditions is characterized by a southeasterly flowing polar air mass colliding with a warmer tropical air mass. The resulting moisture flows are believed to channel up to 90 % of all meridional flow of moisture from the tropics into the midlatitudes, and with fluxes greater than 10^{8} kg/sec.

The requirements for mission success in observing atmospheric rivers are at least one flight, and preferably two, during which a series of 2 - 6 cross sections of an AR are flown. Each cross-section should be ~300-700 nm in length, and crossing orthogonally to the frontal boundary where an AR is anticipated. The ARs occur WSW to WNW of the coast of California and can only be predicted a day or two in advance. Northern Pacific water vapor and cloud imagery from SSM/I, AMSU, and GOES satellites will be monitored on a semi-diurnal basis to determine the existence and probable AR location.

The flights should be at 40,000 ft to 45,000 ft altitude to obtain maximum benefit of the profiling capabilities of the PMVS radiometers. Egress to the Pacific and ingress back to the mainland near a west coast radiosonde site at ~40,000 ft - 45,000 ft is necessary for calibration purposes. Radiosonde sites at Pt. Mugu, San Nicholas Island, Edwards AFB (EAFB), or Vandenburg AFB

(VAFB) could be used, although the preferred egress/ingress waypoint is as close to Pt. Mugu as permissible.

It must be stressed that the likelihood of AR occurrence diminishes significantly starting in early-to-mid April. Accordingly, it is important to be prepared to conduct even a short (12 hour) atmospheric rivers mission as early as possible, and even in late March if the meteorological conditions suggest an occurrence.

2) Sounding Curtain Demonstration. Calibration of a UAV-based microwave sounder for LLJ forecasting purposes is best accomplished by referencing the retrieved profiles to coincident radiosonde profiles. The radiosonde profiles provide the capability of the microwave radiometer to generate a "sounding curtain" extending along the flight line and anchored by the radiosonde waypoints. In this manner the vertical resolution and absolute accuracy of the raob is transferred to the microwave soundings, while the microwave soundings provide high horizontal resolution in between drops without the need for additional expendables.

To demonstrate the sounding curtain, aircraft data are needed over a long flight line that includes at least two coincident radiosonde launches, and preferably three, with waypoints over both land and water. A flight having one or more segments connecting San Nicholas Island, Pt. Mugu, Vandenberg AFB, and Edwards AFB with coincident timed sonde launches would provide the necessary data.

2.3.2 Passive Microwave Vertical Sounder Secondary Objectives

1) Real-Time Sounding for Forecasting Purposes. The utility of UAV-based soundings of land falling weather (either low-level jets or hurricane rainbands) depends on the ability to transfer data back to forecasters in near-real time. The rapid return of data is particularly important for long-endurance UAV flights wherein real-time refinement of observational goals might be warranted. Compression of the decimated and partially processed sounding data presents the most straightforward means of relaying this data within the bandwidth constraints of a UAV. During the atmospheric rivers sectional flights and sounding curtain flight, the PMVS sensor data will need to be accessible via telnet and FTP off-site from Altair operations at Gray Butte Airfield. Bursts of raw data will be transferred during flight to better understand the AR structure and its synoptic environment. The real-time link will also be used to monitor the OC & PMVS sensor health.

3.0 Operational Instruments and Objectives.

3.1 Cirrus Digital Camera System (DCS).

J. Sellars, T. Jacobs, Principal Investigators

Description: True color camera, 4072 x 4072 pixels (400-700 nm, 34° FOV)
Observables: 1) Shoreline mapping, 2) Along-shore/inland feature characterization for habitat mapping/ecosystem monitoring.

The Cirrus DCS optical camera is to be used to provide digital imagery for assessing the capabilities of Altair for surveillance and surveying of the National Marine Sanctuaries (see **Table 2**). The DCS provides image collection in true color or color infrared (CIR). The DCS is a proven technology on UAVs and offers the resolution needed to delineate shoreline and habitat. Using the Cirrus DCS 60mm lens at 13,000 ft will provide 0.60 m resolution, 2.5 km swath, and 60% stereo overlap coverage with 14.5 sec between images at 130 kts airspeed. The lower airspeeds of Altair will provide greater frame overlap.

Flights must be in clear weather and daytime, with visibility greater than 8 miles and with the sun angle above 30 degrees above the horizon. Imagery shall not be attempted where the ground is obscured by clouds, haze, smoke, smog, dust, sleet, rain, etc. Also, imagery shall not be conducted when the ground, and especially land-water interface, is covered by water (flood), snow, or ice. Photography should be collected while the sun is over the water so that any shadows created by elevated objects will point inland and will not obscure the shoreline. The size and number of hot spots (no sun shadow points) and "sun spots" (bright, sun reflectance areas) on the water and shoreline must be kept to a minimum and eliminated if possible because these bright spots can obscure important features. During flight planning, flight line directions and times should be arranged to preclude the occurrence of these spots in critical areas of the photographs (especially shoreline and near shoreline areas).

3.1.1 Cirrus Digital Camera System Primary Objectives

1) Prove platform capabilities for collecting mapping quality data. An altitude of 13,000 ft over shoreline and landmass is sufficient to provide digital imagery suitable for mission success. Flight lines will be designed to support photogrammetric compilation of the shoreline and features. The requirement for coverage is all of the Channel Islands National Marine Sanctuary (CINMS) to include San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands.

3.1.2 Cirrus Digital Camera System Secondary Objectives

1) Shoreline feature attribution. If possible, imagery of the entire extent of the islands is also desired as this will allow attribution of alongshore and inland features of interest. These will include habitat areas of interest to CINMS managers such as vegetation, breeding grounds, rookeries and public use areas.

2) Enforcement/Surveillance. During operations with the Wescam SkyBall, the DCS will be activated to acquire imagery of active fishing vessels as well as non-fishing vessels. These vessels will be spotted and targeted by the Wescam SkyBall.

3.2 Wescam 14 EO/IR SkyBall Camera

J. Sellars, T. Jacobs, Principal Investigators

Description: Camera with 1) Forward looking infrared (FLIR), 2) Electro-optical lens
Observables: 1) Day/night fisheries surveillance/enforcement, 2) Marine mammal surveys

The Wescam 14 Electro-Optical Infrared (EO/IR) "SkyBall" Sensor contains three instruments for exploiting visible and non-visible wavelengths. Two channels operate in the visible (color zoom and monochromatic spotter) and one in the infrared. This provides day/night assets that can be used for fisheries enforcement as well as reconnaissance. Flights at 15,000 to 20,000 ft will be flown over the entire Channel Islands National Marine Sanctuary (CINMS) for a resolution of ~1.5" to ~1.8" respectively. Lower flights are required for specific identification of commercial and recreational fishery vessels, large commercial vessels, and other items of interest (marine mammals, marine debris, etc) that are in or transiting the sanctuary waters.

3.2.1 EO/IR Skyball Camera Primary Objectives

1) Surveillance/Enforcement. The primary goal is to prove the Wescam's EO/IR capabilities for surveillance/enforcement of fisheries regulations. Flight in and out of inclement weather is preferred, as is both night and day operations, to prove capability. A real-time downlink as well as an ability to view images over the Internet is required for enforcement purposes. Prove ability to properly identify and position targets as well as transmit data.

3.2.2 EO/IR Skyball Camera Secondary Objectives

1) Examine capabilities for marine mammal surveys. Prove multiple use platform capabilities by utilizing the EO sensor to perform marine mammal surveys during DCS photogrammetric collection. The zoom lens will be used to monitor activities around the UAV during the photo collection and the spotter lens will be employed for mammal identification.

4.0 Flight Planning Information

Altair operating range. The flights of the Altair during the demonstration project will be located within the shaded region in **Figure 2**. The operating range is set by the scientific and operational requirements of the mission objectives and is constrained by the Altair performance specifications and the requirement of a Ku-band Over the Horizon (OTH) Satellite Communication (SATCOM) link to the Altair. The range includes Gray Butte Airfield (34^{o} 36'N, 117^{o} 36W) where the Altair take-offs and landings will occur and Edwards Air Force Base (AFB) (34^{o} 54'N, 117^{o} 53'W) where the Altair ascents and descents from cruise altitudes will occur. Scientific locations of importance include the Table Mountain Observatory (34^{o} 23'N, 117^{o} 41'W) near Gray Butte Airfield and the Trinidad Head Observatory (41^{o} 3'N, 124^{o} 9'W) on the coast of northern California. A requirement for Altair operations is that a chase aircraft for flight altitudes below 18,000 ft.

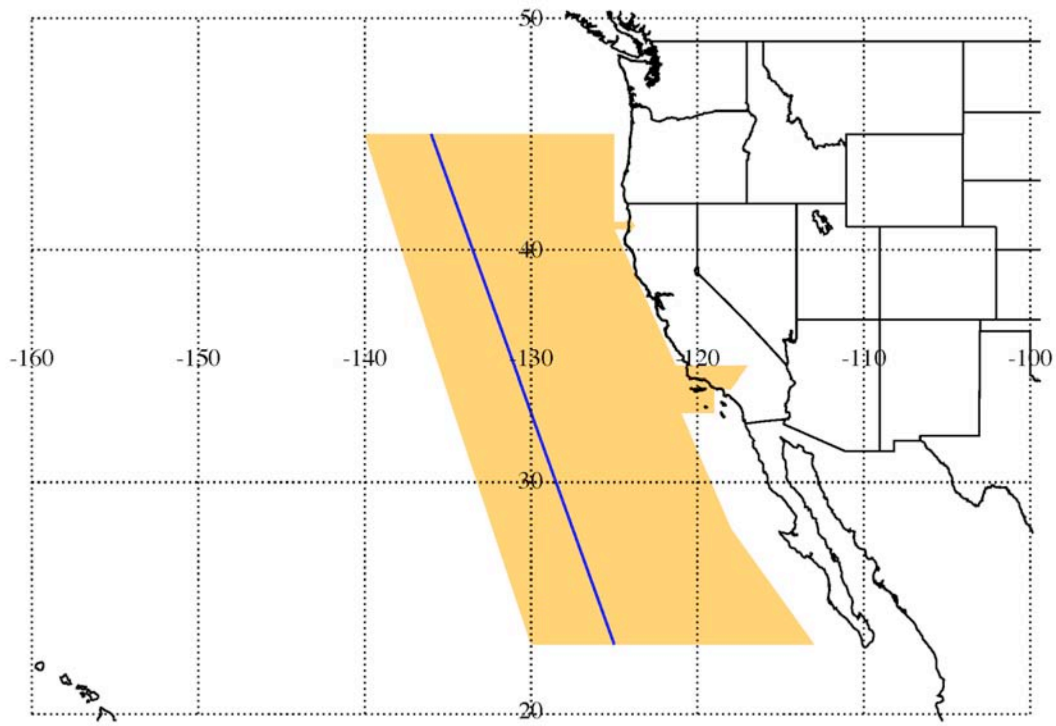


Figure 2. Planned operations range (shaded region) for the Altair UAV during the demonstration mission as requested in the Certificate of Authorization (COA) submitted to the Federal Aviation Administration (FAA). See Section 5.0 for boundary coordinates. The Altair deployment site is Gray Butte Airfield in southern California (34.6N, 117.6W). The blue line marks the approximate western edge of the Ku-band satellite communication (SATCOM) region for satellite AMC 5 located over the equator at 79W longitude. Altair operations to the west of the blue line are uncertain due to expected low SATCOM signal strengths.

Aircraft operations between 29,000 ft and 41,000 ft in international airspace now require special equipment and certification to meet the new Reduced Vertical Separation Minimum (RVSM) provisions. RVSM reduces aircraft separation from 2000 ft to 1000 ft to allow more flight levels. Because the Altair UAV has not yet been certified to meet the new RVSM provisions, the demonstration flights must remain above or below the altitude range of 29,000 ft to 41,000 ft except in specially restricted airspace. The Altair flight plans included in this document meet this requirement. Transitions between 29,000 ft to 41,000 ft are planned only in the restricted airspace controlled by either Edwards AFB or Vandenberg AFB.

Altair performance specifications. The Altair UAV will be operated for up to 21 hrs at altitudes up to 45,000 ft (13.7 km). The instrument payload will be approximately 300 lbs (140 kg). The Altair true air speed ranges from 150 – 200 kts (77 – 103 m/s or 172 – 230 mph) increasing with altitude and reaching a near constant value above about 20,000 ft. For a 20 hr mission (2 hr climb/descent, 18 hr cruise), the operating range (round trip) will be approximately 1350 - 1800 nm (2490 - 3320 km) and the total distance covered will be 2700 - 3600 nm (5000 - 6640 km). Winds at cruise altitude and time-on-station will affect the operating range on individual flights. Altair operations below 18,000 ft will require a piloted aircraft to accompany the Altair throughout the flight.

Basic flight plan set. A basic flight plan set has been developed to fulfill the scientific and operational mission objectives outlined above. The set is summarized in **Table 3**. Details of individual flight plans are shown in **Section 5**. The integration test flights will provide several opportunities test the instrument payload operation and communications in flights throughout the Altair altitude range. The six mission flight plans include those features deemed necessary to meet the list of mission objectives and, hence, are expected to be representative of the actual Altair flights. The actual flight plans, which will be designed for a total duration of 53 hours, will depend a wide range of variables. Principal among them will be meteorological conditions at the Gray Butte Airfield and along the flight track. Meteorological models and datasets will be used to predict conditions that will affect aircraft performance at takeoff and landing and along the flight track.

4.1 Integration Test Flights

A series of integration test flights will be conducted locally from Gray Butte, over the Edwards AFB area before the planned mission flights in April 2005. A minimum of 3 operating flight hours is required for the instrument checkout.

Mission Goals: Functional test of all sensor systems. Tests include detailed instrument performance, data acquisition and storage, and data transmission to the ground through the Altair communications link. Instrument performance will be checked at the low pressures and temperatures present at cruise altitudes with flights of several hour duration.
Mission Location: Primarily in the Gray Butte and Edwards AFB restricted airspace and perhaps short distances off the California coast.
Mission Profile: Various altitude profiles from 1000 ft to 41,000 ft and cruise segments with duration of up to several hours.

Table 3. Summary of Altair Flight Plans[1]

Flight	Description	Approx. Duration	Specifications
	Integration test flights	22 hrs	**Goals:** Functional test of all sensor systems. **Location:** Restricted air space over Gray Butte and Edwards AFB
Flight 1a	**Channel Islands Survey/OC Spiral**	6 hrs	**Goals:** Attempt to duplicate or exceed survey accuracy of manned missions. Evaluate the utility of UAVs as platforms for marine enforcement surveillance. Perform OC sensor calibration profile. **Location:** The airspace above and around the CINMS, with preference to the four northern Channel Islands (Anacapa, Santa Cruz, Santa Rosa, San Miguel.)
Flight 1b	**Channel Islands Survey/Day-Night**	4 hrs	**Goals:** Record fishing and boat activity during daylight and nighttime hours. Identify and record general vessel activity within CINMS and evaluate the EO/IR's ability to identify fishing activity and marine mammals. **Location:** Location will focus on the four northern Channel Islands and Santa Barbara Channel. (Exact geographic areas to be determined by daily fishing and shipping activity.)
Flight 2	**Sounding Curtain/ Atmospheric Chemistry**	6 hrs	**Goals:** Retrieve vertical profiles of temperature and water vapor between radiosonde launch locations. Sample the tropopause region. **Location:** Near the Channel Islands off the coast of California.
Flight 3	**Cross-Tropopause Sampling**	12.5 hrs	**Goals:** Use the GC/OZ instrument to sample polar air masses and to demonstrate the potential of validating Aura satellite retrievals and estimating the age of air in the lowermost stratosphere. **Location:** Up to 400 nm off the California Coast.
Flight 4	**Atmospheric River Sampling**	21 hrs	**Goals:** Profile along and across an atmospheric river approaching the California coast. Sample tropopause region. **Location:** Up to 1000 nm off the California Coast.
Flight 5	**Ocean Color Profile/Trinidad Head Profile**	11 hrs	**Goals**: Perform vertical profiles over blue ocean and near Trinidad Head Observatory. **Location:** Up to 200 nm off the California coast.

[1]The actual Altair mission flights will have a total duration of 53 hours. These flight plans include those features deemed necessary to meet the list of mission objectives. Actual flight plans will be modified to take into account meteorological and other conditions on the day of flight.

4.2 Scientific and Operation Mission Flights

4.2.1 Flight 1a: Channel Islands Survey/OC Spiral (~ 6 hours)

This flight will attempt to duplicate or exceed the accuracy of manned survey flights currently taking place in the Channel Islands National Marine Sanctuary (CINMS). Flights will take place at 13,000 ft and 130 KIAS, flying transects (see attached proposed transect pattern) around the Northern Channel Islands. In addition, a vertical profile for the ocean color sensor will be made south of the islands.

Mission Goals: Fly over all of the islands in the CINMS (San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands) following flight lines designed to support photogrammetric compilations of shorelines. Simultaneously, operate the Wescam 14 EO/IR, to fly reconnaissance flights and attempt to spot and identify marine mammals. Make a vertical profile over blue ocean water to obtain data for OC radiance correction and to obtain trace gas profiles from GC/OZ.

Mission Location: The airspace above and around the CINMS, with preference to the four northern Channel Islands (Anacapa, Santa Cruz, Santa Rosa, and San Miguel.)

Mission Profile: Fly east/west transects over CINMS at 13,000 ft. Make spiral vertical profile from 2000 ft to 29,000 ft. **Figure 3** shows the geographical location of the Channel Islands.

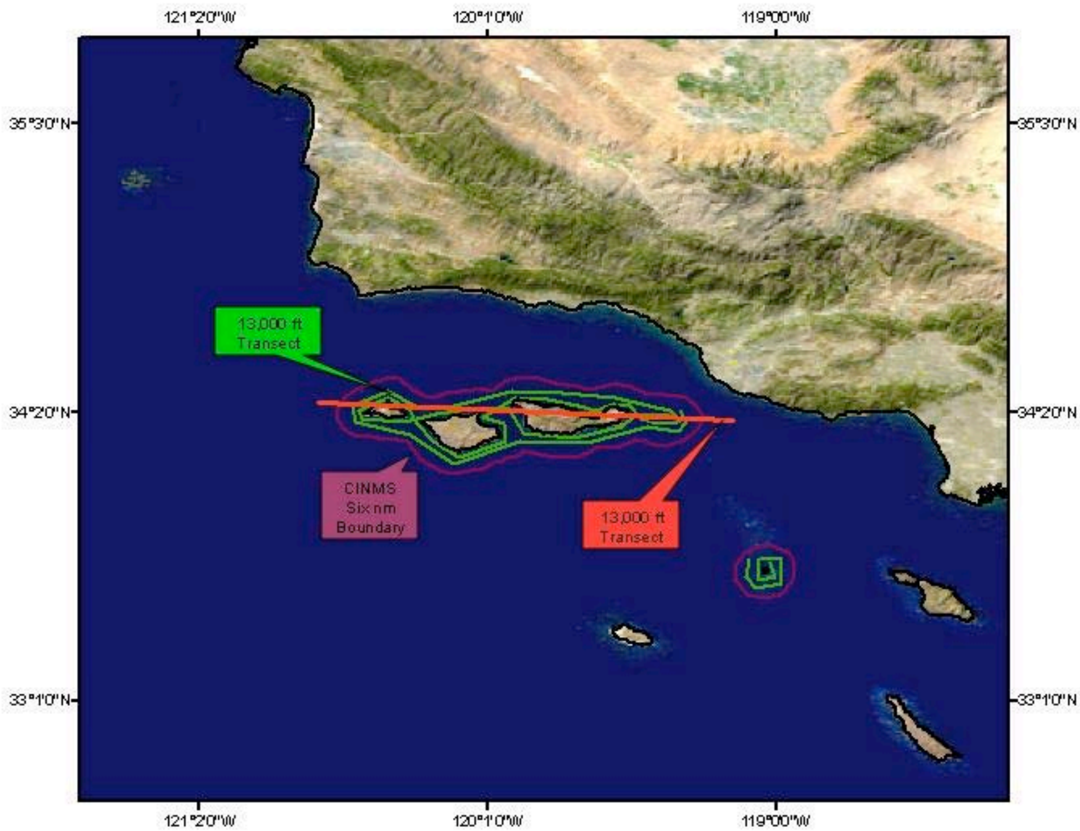


Figure 3. Detailed projection of possible Channel Islands flight tracks. The 13,000 ft altitude line (red) is to be flown westward, while the 13,000 ft line (green) is flown eastward, but meandering along the northern and southern shores to obtain as much high-resolution near-shore imagery as possible.

4.2.2 Flight 1b: Channel Islands Survey/Day - Night (~ 4 hours)

This flight will demonstrate day-to-night operations to capture imagery of fishing activity by capturing visible light boat reflectance and infrared imagery. Flights at 13,000 ft will be flown over the entire Channel Islands National Marine Sanctuary (CINMS) for a image resolution of greater than 1.5". Lower flights maybe required for specific identification of commercial and recreational fishery vessels, large commercial vessels, and other items of interest (marine mammals, marine debris, etc) that are in or transiting the sanctuary waters.

Mission Goals: Demonstrate day-to-night operations to utilize the EO/IR to survey fishery vessel use patterns in the CINMS. Attempt to duplicate or exceed accuracy and image resolution of manned survey missions by recording and identifying vessel types, locations, and activities and evaluate utility of UAVs as platforms for marine enforcement surveillance.
Mission Location: Location will focus on the four Northern Channel Islands and Santa Barbara Channel. (Exact geographic areas to be determined by daily fishing and shipping activity.)
Mission Profile: Fly over areas of fishing activity and record images. Utilize figure-8 loop around the Northern Channel Islands. **Figure 3** shows the geographical location of the Channel Islands.

4.2.3 Flight 2: Sounding Curtain/Atmospheric Chemistry (~ 6 hours)

This flight will demonstrate how radiosonde observations can be used to enhance the precision accuracy of the PVMS retrievals of moisture and temperature and provide an opportunity to sample long-lived gases near the tropopause with the GC/OZ instrument and compare with ground-based measurements at Table Mountain Observatory. The sounding curtain segments will extend between radiosonde launch locations on Point Magu, San Nicholas Island, Edwards AFB, and Vandenberg AFB. Radiosonde launches will be coordinated with planned aircraft overflight times.

Mission Goals: Retrieve vertical profiles of temperature and water vapor between radiosonde launch locations. Sample the tropopause region.
Mission Location: Near the Channel Islands off the coast of California.
Mission Profile: Ascend to 41,000 ft ft at Edwards ABF and then proceed sequentially to a location near Point Magu on the California coast, San Nicholas Island, and Vandenberg AFB. Return to base and pass near the Table Mountain Observatory prior to descent.

4.2.4 Flight 3: Cross-Tropopause Sampling (~12.5 hours)

This flight will demonstrate that long-lived gases can be sampled in situ in the tropopause region. The tropopause divides the troposphere, the lowest region of the atmosphere, from the stratosphere. The two regions show distinct differences in chemical composition. The opportunity to cross the tropopause at mid latitudes in spring will provide an opportunity to sample these differences.

Mission Goals: Use the GC/OZ instrument to sample polar air masses that have been transported from higher latitudes as a result of the breakdown of the Arctic winter vortex (see **Figure 4**). The location of polar air depends on the exact meteorological conditions during the breakup. Use measurements of the halogenated gases, ozone, and nitrous oxide to demonstrate the potential of validating Aura satellite retrievals and of estimating the age of air in the lowermost stratosphere.
Mission Location: Up to 400 nm off the California Coast.
Mission Profile: Ascend to 41,000 ft and then proceed to a location about 200 nm off the California coast. Proceed along the coast about 500 nm to northern California and turn west to the 127W meridian. Proceed southward along the meridian for 400 nm and then return to base.

On long northbound transit leg, the aircraft will cruise climb between 41,000 ft and maximum altitude in order to optimize sampling of stratospheric air.

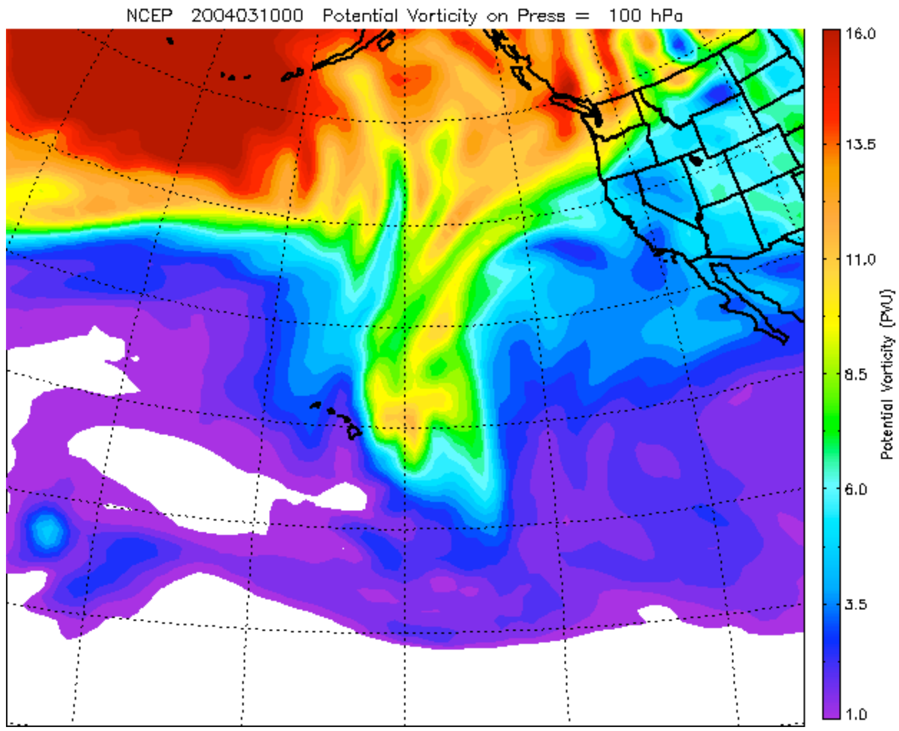


Figure 4. Map of potential vorticity for 10 March 2004 as analyzed on the 100 hPa pressure surface. Values above 2 PVU (see color scale) are associated with stratospheric air. High PVU values at mid latitudes have been transported from the Arctic polar vortex region at high latitudes.

4.2.5 Flight 4: Atmospheric Rivers Sampling (~ 21 hours)

This flight will demonstrate that the detailed cross-sectional moisture content of northern Pacific atmospheric rivers and their embedded low-level jets off the coast of California can be quantified. These moisture flows and the low-level jets typically associated with them can bring hazardous amounts of precipitation to coastal areas of the U.S. (see **Figure 5**). They occur near the coast once every ~1.5 to ~3 weeks and last up to approximately 3 days. The PMVS will provide measurements of total integrated water vapor and the vertical profile of water vapor and temperature in and near an atmospheric river. This flight will also provide another opportunity for the GC/OZ instrument to make valuable measurements in the tropopause region and for the OC instrument to observe blue ocean water. The opportunity to sample an atmospheric river will depend on changes in the seasonal and daily meteorological fields in the equatorial and mid latitude regions of the middle and eastern Pacific Ocean, and especially on the occurrence of cyclonic activity in the northern Pacific.

Mission Goals: Profile along and across an atmospheric river approaching the California coast. Sample tropopause region.

Mission Location: Up to 1500 nm off the California Coast.
Mission Profile: Ascend to 41,000 ft over Edwards AFB and then proceed to a location about 200 nm off the California coast near an atmospheric river. Pass as close as permissible to the Pt. Mugu radiosonde site en route. Begin a flight pattern that crosses the atmospheric river flow in an orthogonal direction (most likely in a SE to NW direction). Proceed parallel to the atmospheric river and then again profile across the river. Return to coast by transiting along the river core region. Return to base, again passing as near as permissible to the Pt. Mugu radiosonde site and descending over Edwards AFB. Radiosondes will also be launched at Edwards AFB both on ascent and descent.

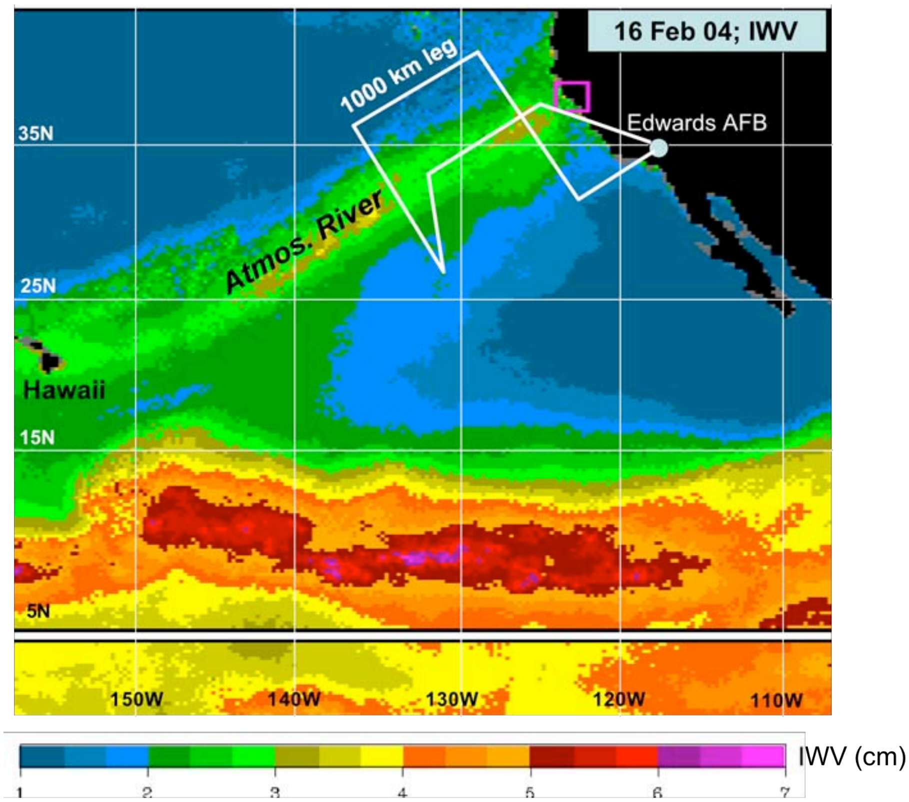


Figure 5. Integrated water vapor (IWV) measurement from the Special Sensor Microwave Imager (SSM/I) satellite instrument. The IWV amounts show an atmospheric river bringing water vapor to the California coast in February 2004. A notional flight plan to remotely sense the river is shown as the white line.

4.2.6 Flight 5: Ocean Color Profile/Trinidad Head Profile (~ 11 hours)

This flight will provide needed calibration for the Ocean Color sensor and the GC/OZ instrument. Ocean color allows chlorphyll-a levels to be determined in ocean surface waters (see **Figure 6**). The Ocean Color sensor requires profiles to make radiance corrections to account for ambient aerosol loading in the observation column. The GC/OZ instrument measurements will be compared with those made by instruments that routinely operate at the Trinidad Head Observatory.

Mission Goals: Perform vertical profiles over blue ocean and near Trinidad Head Observatory.
Mission Location: Up to 200 nm off the California coast.

Mission Profile: Ascend to 29,000 ft and then proceed to a location within 200 nm off the California coast in the controlled airspace of Vandenberg AFB. Perform vertical profile to near surface and back and then proceed along the coast to Trinidad Head Observatory. Perform vertical profile to 18,000 ft and back and then return along outbound track to base.

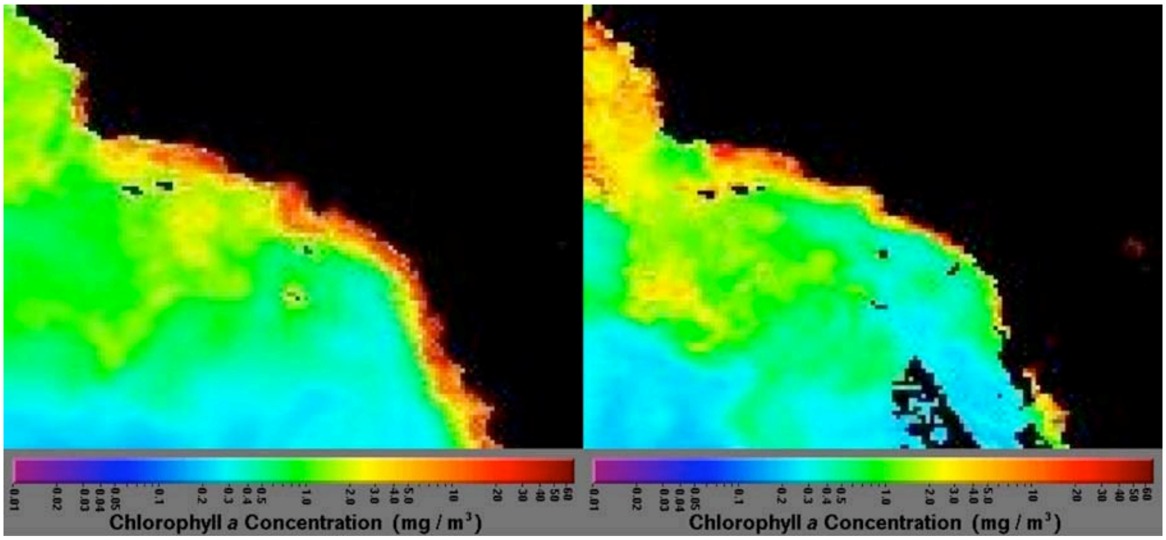
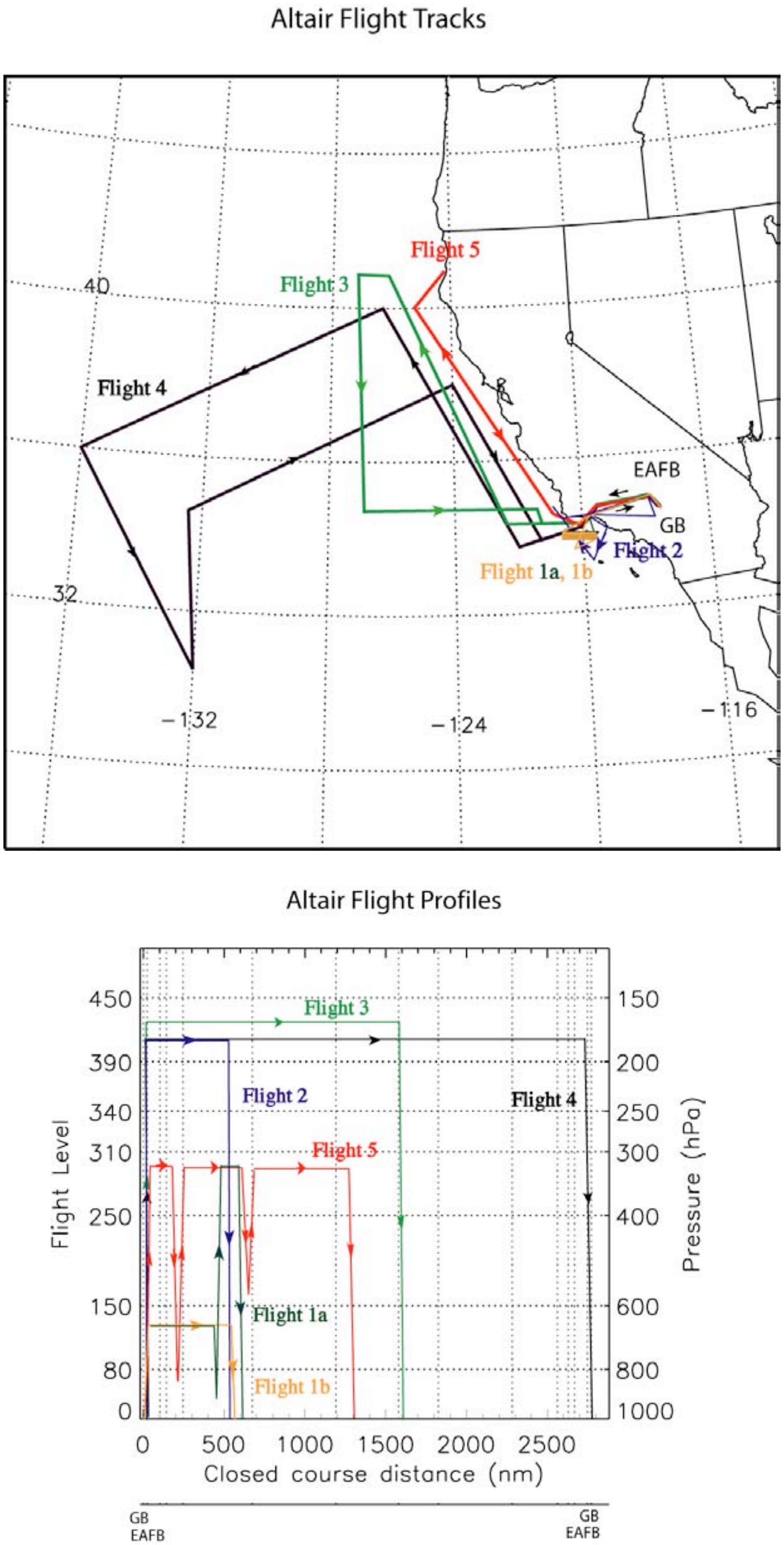


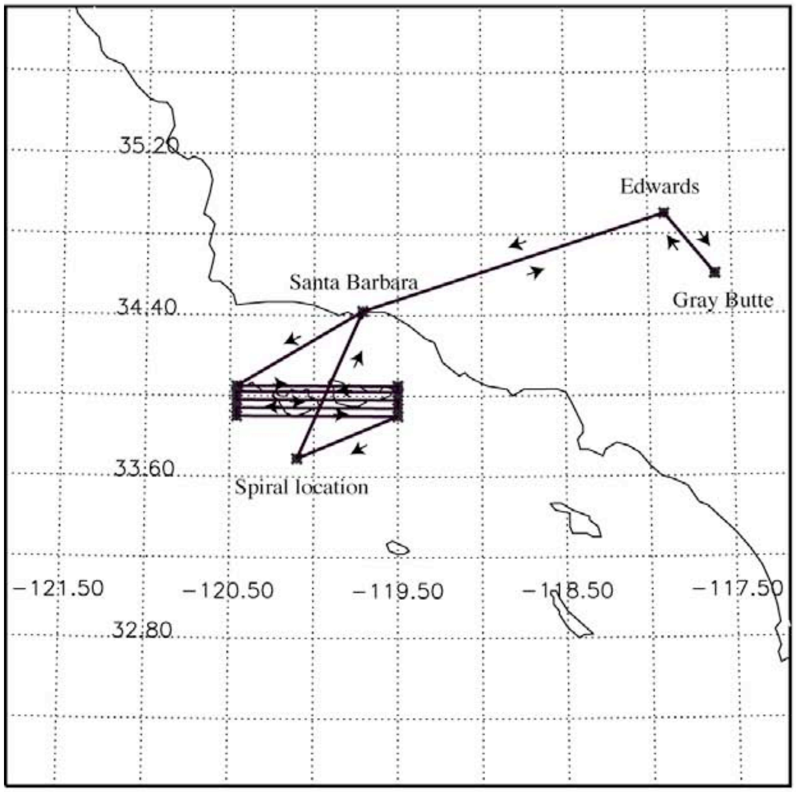
Figure 6. MODIS weekly composites of chlorophyll-a concentration from (a) March 2003 (left), and (b) March 2004 (right). The images show strong seasonal changes in primary production due to eddy-induced thermal structure.

5.0 Altair Flight Plans: Flight tracks, flight profiles, and flight waypoints

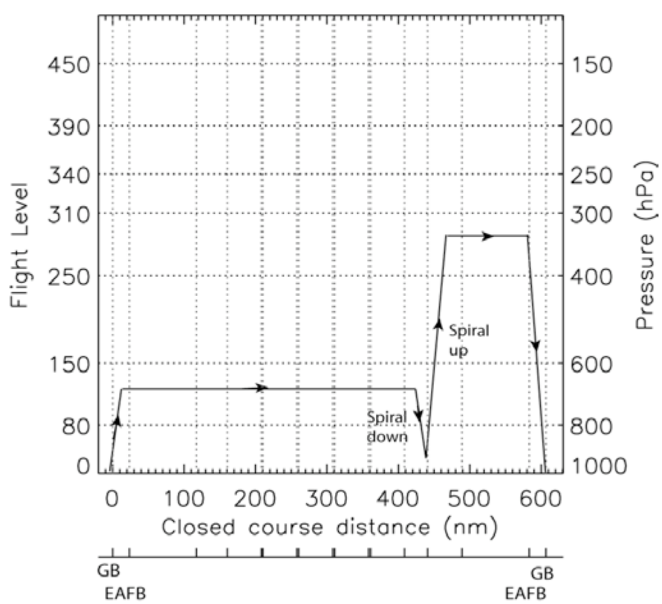


Composite flight tracks and flight profiles

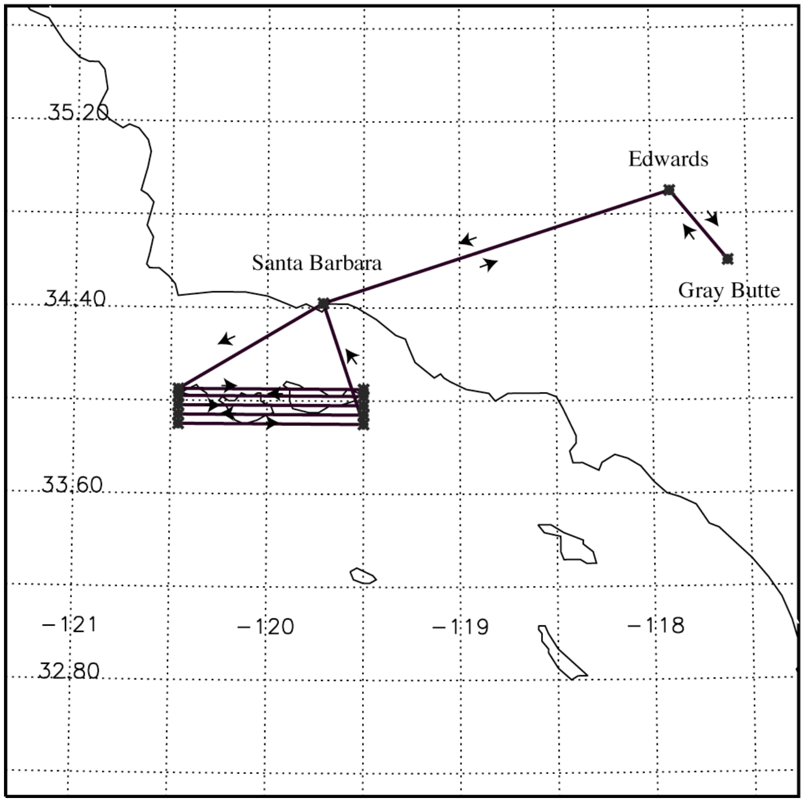
Flight 1a: Channel Islands Survey/Ocean Color Spiral



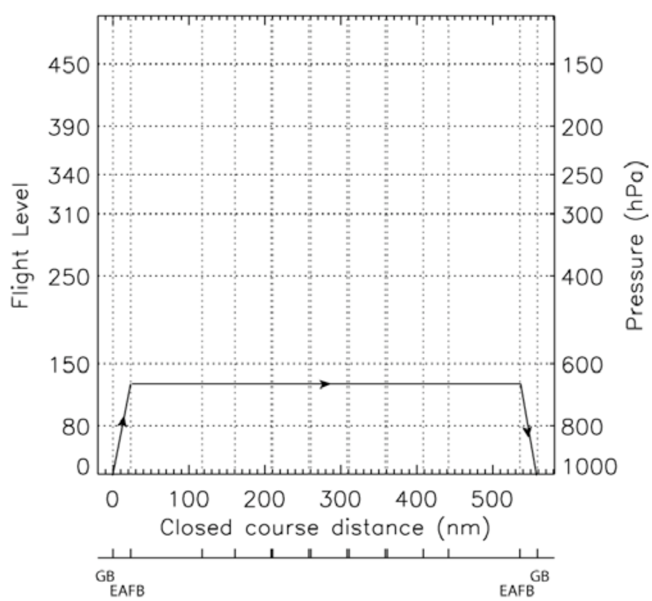
Flight 1a: Channel Islands Survey/Ocean Color Spiral



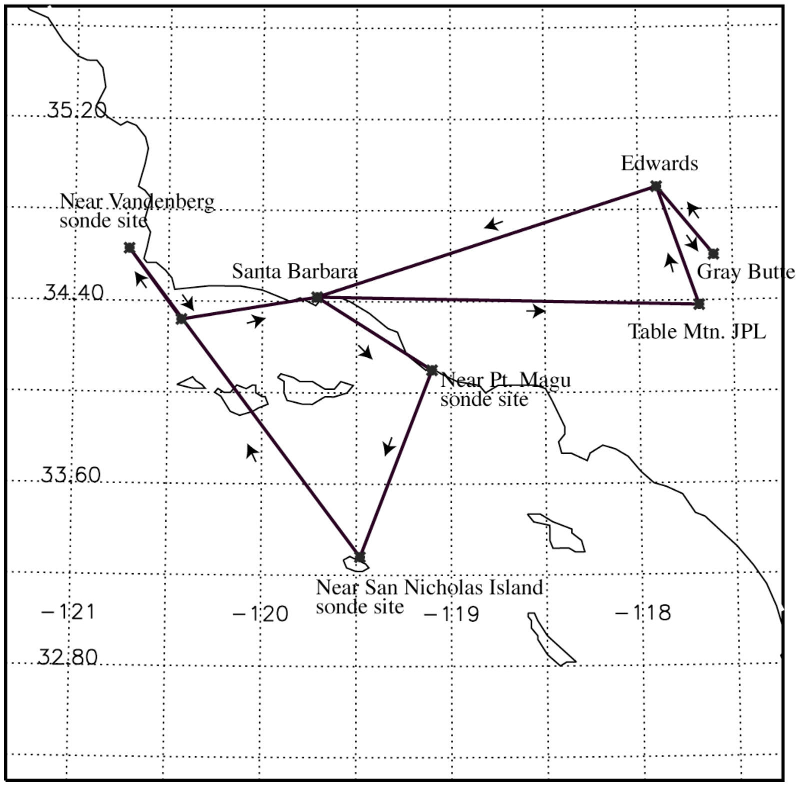
Flight 1b: Channel Islands Survey/Day-Night



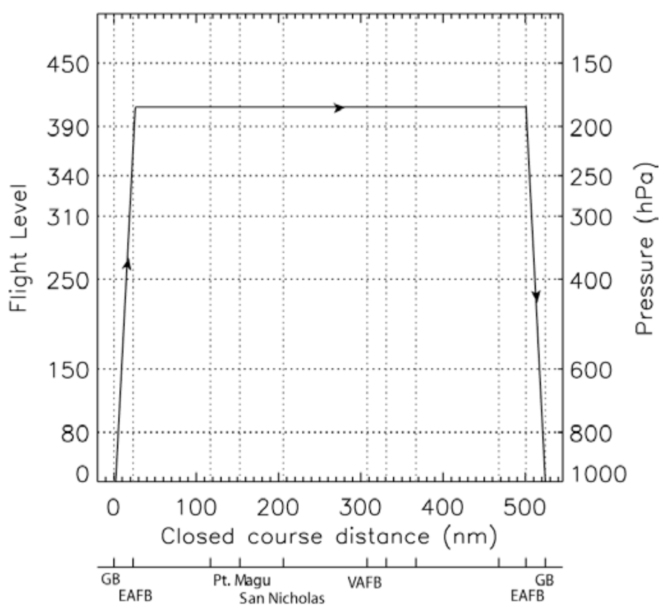
Flight 1b: Channel Islands Survey/Day-Night



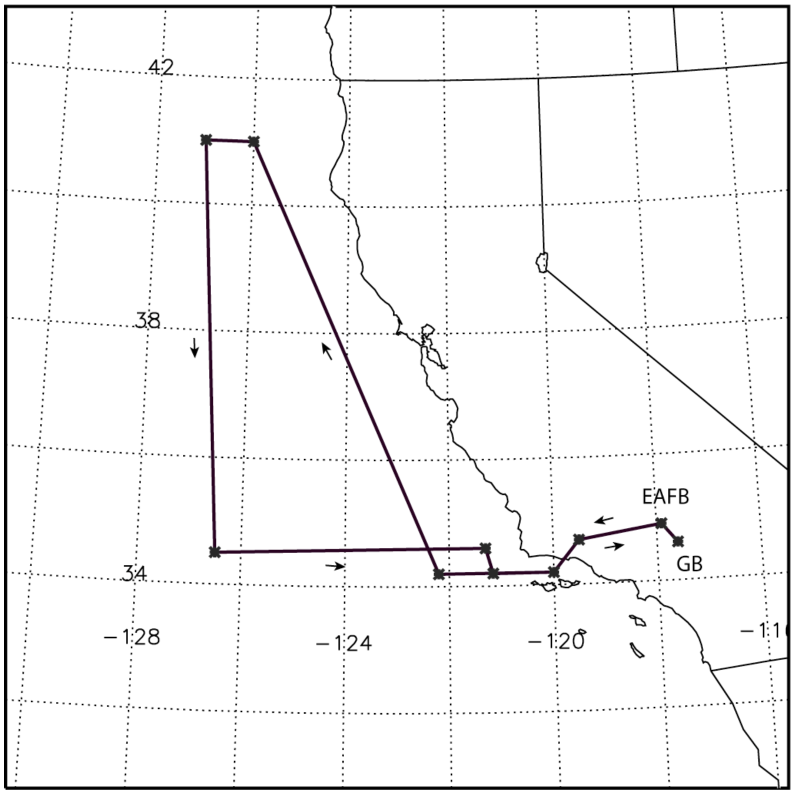
Flight 2: Sounding Curtain/Atmospheric Chemistry



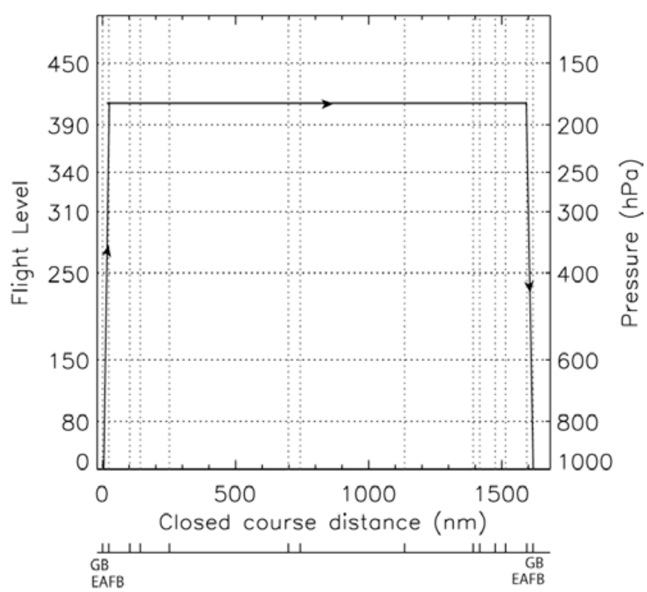
Flight 2: Sounding Curtain/Atmospheric Chemistry



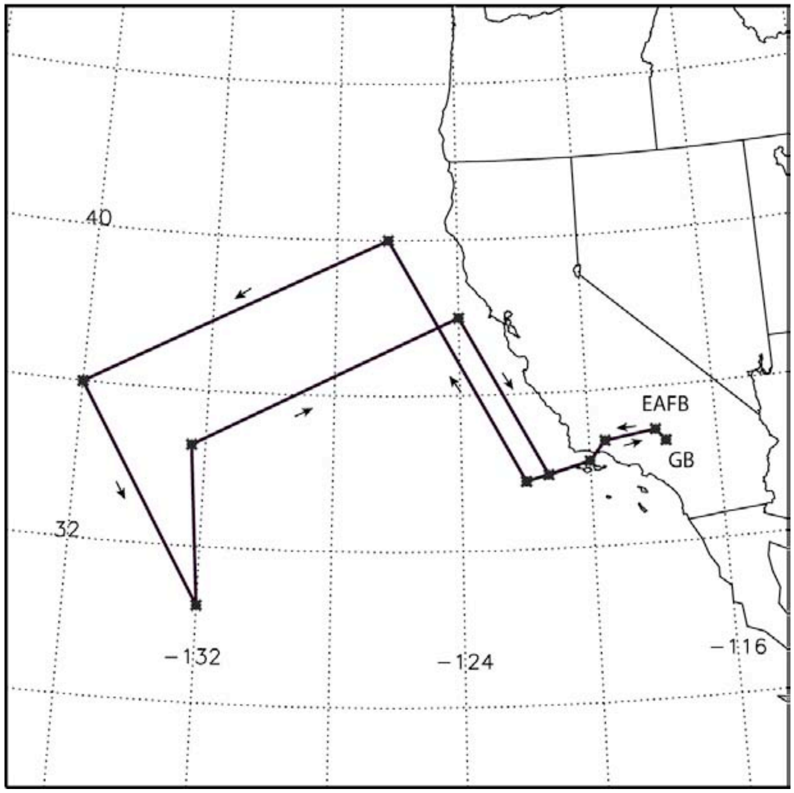
Flight 3: Cross-Tropopause Sampling



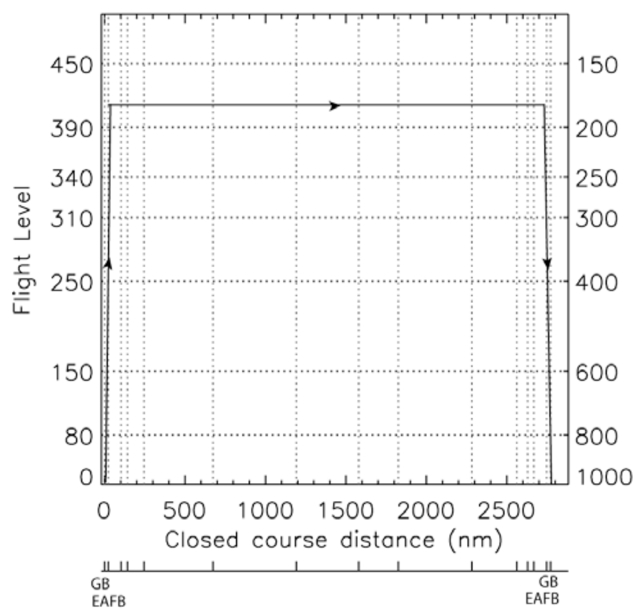
Flight 3: Cross-Tropopause Sampling



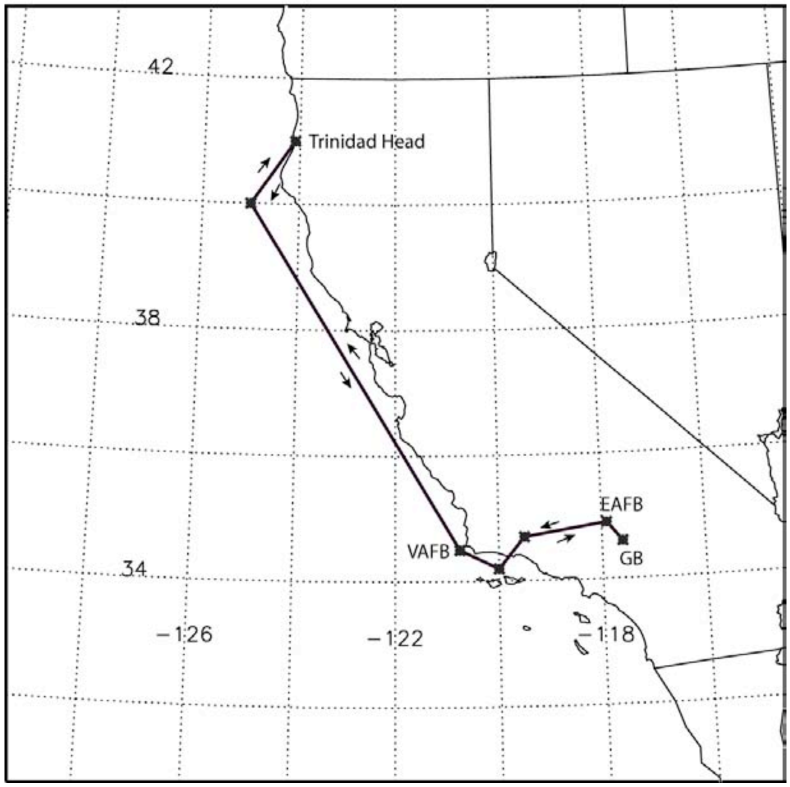
Flight 4: Atmospheric River Sampling



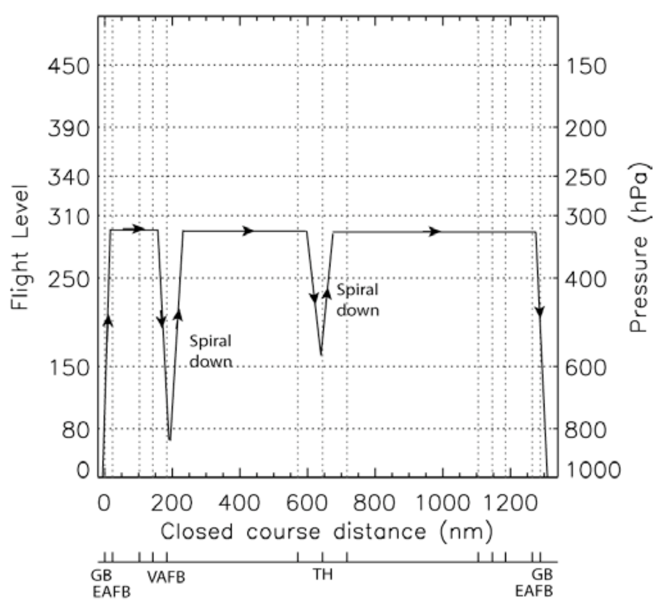
Flight 4: Atmospheric River Sampling



Flight 5: Ocean Color Profile/Trinidad Head Profile



Flight 5: Ocean Color Profile/Trinidad Head Profile



Flight 1a: Channel Islands Survey/Ocean Color Spiral Waypoints

Waypoint	Lat	Lon	Distance (nm)	Altitude (kft)	Elapsed Time	Notes
GB	34.60 N	117.60 W	0	0	0	Gray Butte
EAFB	34.90 N	117.90 W	23	13	:20	Edwards AFB
	34.42 N	119.71 W	118	13	1:00	Santa Barbara
	34.05 N	120.46 W	161	13	1:15	Start island survey
	34.05 N	119.50 W	208	13	1:38	
	34.02 N	119.50 W	210	13	1:39	
	34.02 N	120.46 W	258	13	1:56	
	33.98 N	120.46 W	261	13	1:57	
	33.98 N	119.50 W	308	13	2:15	
	33.94 N	119.50 W	310	13	2:16	
	33.94 N	120.46 W	357	13	2:34	
	33.90 N	120.46 W	359	13	2:35	
	33.90 N	119.50 W	406	13	2:53	End island survey
	33.69 N	120.10 W	442	2-29	3:15	Spiral profile location
	34.42 N	119.71 W	490	29	4:15	Santa Barbara
EAFB	34.90 N	117.90 W	550	29	4:40	Edwards AFB
GB	34.60 N	117.60 W	573	0	5:28	Gray Butte

NOTE: Flight times assume true ground speed of 150 knots. Descent rate is assumed to be roughly 600-800 ft./minute. Estimated 10 minutes to ascend to FL130, 48 minutes to descend from FL290, 20 minutes to descend from FL130 to FL20, 24 minutes to ascend from FL20 to FL290.

Flight 1b: Channel Islands Survey/Day-Night Waypoints

Waypoint	Lat	Lon	Distance (nm)	Altitude (kft)	Elapsed Time (hrs)	Notes
GB	34.60 N	117.60 W	0	0	0	Gray Butte
EAFB	34.90 N	117.90 W	23	13	:20	Edwards AFB
	34.42 N	119.71 W	118	13	1:00	Santa Barbara
	34.05 N	120.46 W	161	13	1:15	Start island survey
	34.05 N	119.50 W	208	13	1:38	
	34.02 N	119.50 W	210	13	1:39	
	34.02 N	120.46 W	258	13	1:56	
	33.98 N	120.46 W	261	13	1:57	
	33.98 N	119.50 W	308	13	2:15	
	33.94 N	119.50 W	310	13	2:16	
	33.94 N	120.46 W	357	13	2:34	
	33.90 N	120.46 W	359	13	2:35	
	33.90 N	119.50 W	406	13	2:53	End island survey
	34.42 N	119.71 W	441	13	3:12	Santa Barbara
EAFB	34.90 N	117.90 W	501	13	3:40	Edwards AFB
GB	34.60 N	117.60 W	524	0	4:02	Gray Butte

NOTE: Flight times assume true ground speed of 150 knots. Descent rate is assumed to be roughly 600-800 ft./minute. Estimated 10 minutes to ascend to FL130, 22 minutes to descend from FL130 to surface.

Flight 2: Sounding Curtain/Atmospheric Chemistry Waypoints

Waypoint	Lat	Lon	Distance (nm)	Altitude (kft)	Elapsed Time (hrs)	Notes
GB	34.60 N	117.60 W	0	0	0	Gray Butte
EAFB	34.90 N	117.90 W	23	41	1:00	Edwards AFB
	34.42 N	119.71 W	118	41	1:40	Santa Barbara
Pt. Magu	34.10 N	119.10 W	154	41	1:55	Near Pt. Magu sonde launch site
S. Nicholas	33.28 N	119.48 W	206	41	2:15	Near San Nicholas Island sonde launch site
VAFB	34.63 N	120.71 W	309	41	2:55	Near Vandenberg sonde launch site
	34.32 N	120.43 W	331	41	3:06	Turn inland
	34.42 N	119.71 W	368	41	3:31	Santa Barbara
Table Mtn.	34.38 N	117.68 W	468	41	4:01	Table Mountain Facility
EAFB	34.90 N	117.90 W	501	41	4:15	Edwards AFB
GB	34.60 N	117.60 W	524	0	5:30	Gray Butte

NOTE: Flight times assume true ground speed of 150 knots. Descent rate is assumed to be roughly 600-800 ft./minute. Estimated 10 minutes to ascend to FL130, 22 minutes to descend from FL130 to surface.

Flight 3: Cross Tropopause Sampling Waypoints

Waypoint	Lat	Lon	Distance (nm)	Altitude (kft)	Elapsed Time (hrs)	Notes
GB	34.60 N	117.60 W	0	0	0	Gray Butte
EAFB	34.90 N	117.90 W	23	41	1:00	Edwards AFB
	34.70 N	119.50 W	102	41	1:32	Santa Barbara
	34.20 N	120.00 W	142	43	1:48	Near Channel Islands
	34.20 N	122.20 W	251	43	2:33	Start along-coast leg
	41.00 N	126.00 W	698	43	5:37	Turn west
	41.00 N	127.00 W	743	43	5:55	Start due-south leg
	34.50 N	126.50 W	1135	43	8:36	Turn east to start return
	34.60 N	121.30 W	1392	43	10:22	Turn south
	34.20 N	121.16 W	1417	43	10:32	Turn east
	34.20 N	120.00 W	1475	43	10:56	Near Channel Islands
	34.70 N	119.50 W	1514	43	11:12	Santa Barbara
EAFB	34.90 N	117.90 W	1593	41	11:50	Edwards AFB
GB	34.60 N	117.60 W	1617	0	12:45	Gray Butte

NOTE: Flight times assume true ground speed of 150 knots. Descent rate is assumed to be roughly 600-800 ft./minute.

Flight 4: Atmospheric River Sampling Waypoints

Waypoint	Lat	Lon	Distance (nm)	Altitude (kft)	Elapsed Time (hrs)	Notes
GB	34.60 N	117.60 W	0	0	0	Gray Butte
EAFB	34.90 N	117.90 W	23	41	1:00	Edwards AFB
	34.70 N	119.50 W	102	41	1:32	Santa Barbara
	34.20 N	120.00 W	142	41	1:48	Near Channel Islands
	33.70 N	122.00 W	245	41	2:30	Start across-river leg
	40.00 N	126.30 W	674	41	5:27	Turn SW along river
	36.00 N	136.00 W	1192	41	9:00	Turn SE to cross river
	30.50 N	132.00 W	1579	41	11:39	Turn to reach river center
	34.60 N	132.40 W	1826	41	13:20	Turn to fly along river
	38.00 N	124.00 W	2283	41	16:28	Turn to fly across river
	33.90 N	121.30 W	2561	41	18:23	Turn inland and return
	34.20 N	120.00 W	2629	41	18:50	Near Channel Islands
	34.70 N	119.50 W	2668	41	19:06	Santa Barbara
EAFB	34.90 N	117.90 W	2747	41	19:45	Edwards AFB
GB	34.60 N	117.60 W	2771	0	20:40	Gray Butte

NOTE: Flight times assume true ground speed of 150 knots. Descent rate is assumed to be roughly 600-800 ft./minute.

Flight 5: Ocean Color Profile/Trinidad Head Profile Waypoints

Waypoint	Lat	Lon	Distance (nm)	Altitude (kft)	Elapsed Time (hrs)	Notes
GB	34.60 N	117.60 W	0	0	0	Gray Butte
EAFB	34.90 N	117.90 W	23	29	0:45	Edwards AFB
	34.70 N	119.50 W	102	29	1:17	Santa Barbara
	34.20 N	120.00 W	142	29	1:33	Near Channel Islands
VAFB	34.50 N	120.75 W	183	6-29	2:05	Vandenberg spiral down/up & start along-coast leg
	40.00 N	125.00 W	571	29	5:15	Turn toward coast
TH	41.00 N	124.10 W	644	18-29	5:45	Trinidad Head spiral down/up & start return
	40.00 N	125.00 W	716	29	6:44	Turn along coast
	34.50 N	120.75 W	1104	29	9:24	Vandenberg airspace
	34.20 N	120.00 W	1145	29	9:41	Near Channel Islands
	34.70 N	119.50 W	1185	29	9:57	Santa Barbara
EAFB	34.90 N	117.90 W	1264	29	10:30	Edwards AFB
GB	34.60 N	117.60 W	1287	0	11:15	Gray Butte

NOTE: Flight times assume true ground speed of 150 knots. Descent rate is assumed to be roughly 600-800 ft./minute. Spiral at VAFB assumed to take 45 minutes, spiral at Trinidad Head assumed to take 30 minutes.